LORENTZ MOTOR CONTROL SYSTEM FOR A PAYLOAD

The invention relates to a control arrangement for controlling a plurality of Lorenz motors actuating a payload, the payload having a center of gravity, the control arrangement comprising a controller for receiving height signals from sensors sensing heights of said payload and for calculating control signals for said Lorenz motors from said height signals.

It is known to support a payload with a plurality of, e.g. three or four, mounts. The mounts may each comprise an airmount and one or two Lorenz motors. Instead of airmounts, other type of "springs" may be used. The payload has a center of gravity that may or may not be above the airmounts. In dependence on the design of the airmounts, the critical height of the center of gravity of the payload where the payload gets unbalanced may be lower or higher. Therefore, strict rules apply with respect to allowable upper limit of the height of the center of gravity above the airmounts. As is known to persons skilled in the art, the softer the airmounts or the smaller the base, i.e., distance between the airmounts, the lower the critical height. And, the higher the actual height of the center of gravity of the payload, the higher the airmounts or the greater the distance between the airmounts must be designed.

Another way to cope with this problem, as is also known from the prior art, is to apply some additional horizontal springs engaging side surfaces of the payload and walls opposite to the side surfaces. These springs increase rotational stiffness of the payload and keep it from instability with respect to tilt.

However, there may be locations where there is little room building in additional horizontal springs and an additional frame therefore. Moreover, this may be an expensive solution. When one wishes to replace existing airmounts with softer airmounts the base may already be fixed, etc.

A typical example is a suspension of an electron microscope or (parts) of a lithographic apparatus. For improved floor vibration isolation, softer airmounts are preferred. The height of the center of gravity of such an apparatus requires airmounts to be located

higher or to be located further apart. However, increasing the heights of the airmounts may form obstacles to an operator of the apparatus, and increasing the base may not be allowable, e.g., due to a conflict with an electronics cabinet or for commercial reasons.

Therefore, it is an object of the invention to provide an improved control of the mounts such that the sensitivity of a payload to gravitational instability is reduced without substantially increasing vertical stiffness.

To that end, the invention provides a control arrangement as defined at the outset, characterized in that said controller is arranged to calculate from these height signals at least one angle of rotation of the center of gravity about a horizontal axis and calculate from this at least one angle of rotation said control signals for said Lorenz motors such that a predetermined rotational stiffness for supporting said payload is achieved.

Thus a multiple-input-multiple-output controller is applied that calculates at least one rotation component of the center of gravity of the payload and controls the Lorenz motors to provide additional rotational stiffness without increase of vertical stiffness. It is possible to improve the gravitational stability. The payload may have a higher center of gravity than in prior art systems, without the system becoming unstable.

In an embodiment, the invention relates to a method of controlling a plurality of Lorenz motors actuating a payload, the payload having a center of gravity, comprising receiving height signals from sensors sensing heights of said payload and calculating control signals for said Lorenz motors from said height signals, characterized by calculating from these height signals at least one angle of rotation of the center of gravity about a horizontal axis and calculating from this at least one angle of rotation said control signals for said Lorenz motors such that a predetermined rotational stiffness for supporting said payload is achieved.

Moreover, the invention relates to a computer program product comprising instructions and data to be loaded by a computer, and after being loaded allowing the computer to perform the method as defined above.

Finally, the invention relates to a data carrier comprising such a computer program product.

The invention will be explained with reference to some drawings which are only intended to illustrate the invention and not to limit its scope. The scope is defined by the annexed claims and their technical equivalents only.

Fig. 1 shows a payload supported by a plurality of mounts;

Fig. 2 shows a general, schematic block diagram of a multiple-input-multiple-output control arrangement for the Lorenz motors.

Fig. 1 shows a payload 4 supported by a plurality of mounts. The payload 4 has a center of gravity 12. The mounts comprise airmounts 15, 16, and Lorenz motors 1, 2. For the sake of simplicity, Fig. 1 shows two airmounts 15, 16 and two Lorenz motors 1, 2, however, there will mostly be three or four airmounts and at least one Lorenz motor per airmount. The airmounts support the payload 4, whereas the Lorenz motors 1, 2 are actuated to apply forces as part of a control concept to create vertical servo stiffness and/or servo damping. Additionally, there may be one or more extra Lorenz motors arranged to apply horizontal forces as part of a control concept to create horizontal servo stiffness and/or servo damping, as is evident to persons skilled in the art. These latter Lorenz motors are not of interest to the present invention.

The distance between the Lorenz motors is l.

An x, y, z-axes system is defined having an origin at a predetermined location. A rotation φ is defined as a rotation about the x-axis. The center of gravity 12 is at height h above the Lorenz motors 1, 2.

Fig. 2 shows a control arrangement for control of the two Lorenz motors 1, 2. The control arrangement shown comprises two sensors 6, 7 for sensing heights z_1, z_2, respectively. The sensors 6, 7 feed back height signals z_1, z_2 to a controller 8. The controller 8 calculates control signals C_1, C_2 from these height signals z_1, z_2 for the Lorenz motors 1, 2, respectively. Fig. 2 is simplified in the sense that it shows only two sensors 6, 7, and two input signals and two output signals for the controller 8. In most cases, three z-sensors will be used that provide information as to z, q and a rotation around the y-axis.

For the two Lorenz motors embodiment shown in Fig. 1, the following control concept performed by controller 8 is proposed:

- derive angle φ from z_1, and z_2, e.g., from $(z_1-z_2)/l$
- calculate a torque T from angle φ : $T = -k.\varphi$, where k is a measure of rotational stiffness in Nm/rad

- calculate control signals C_1, C_2 from torque T: $C_1 = -T/a$, and $C_2 = T/b$, where a and b are constants the values of which can be chosen freely but have equal sign.

In an embodiment, a low pass filter may be applied. Then, the torque T is calculated from $T = -k.\varphi.H_{lp}$, where H_{lp} is the low pass filter transfer function.

In a 3-dimensional environment, the general idea is as follows: feed back the height position signals from all height sensors used to the controller 8, calculate angles of rotation about the x-axis and the y-axis from these height position signals, calculate control signals for all Lorenz motors used from these angles of rotation such that a predetermined rotational stiffness is achieved without substantially creating additional vertical stiffness.

As is evident to persons skilled in the art, there may be applied other types of mounts than airmounts, e.g., springs. Moreover, when the airmounts 15, 16 are applied, they will be provided with supply lines to supply air to them. Then, air is supplied by suitable pressure sources also controlled by the controller 8. It is to be understood that the controller 8 is shown as a single unit. However, the controller 8 may be implemented by multiple computers acting together, e.g., in a master-slave configuration. The suitable software may be distributed via data carriers or any other suitable way. Moreover, the controller for the pneumatics part may be independent of the controller for the Lorenz motors.